

## PROCESSOR WITH ASYMMETRIC SIMD FUNCTIONALITY

## BACKGROUND

5 1. Field of the Present Invention

The present invention is in the field of microprocessors and more particularly in the field of microprocessors with single instruction, multiple data (SIMD) capability.

10 2. History of Related Art

Single instruction stream multiple data streams (SIMD) computers and vector processors are both useful in computationally intensive applications such as signal processing. In a SIMD computer, two or more processors (or functional units within a processor) execute the same instruction on different data streams. A vector processor is a processor that can operate on an entire vector with one instruction. Historically, SIMD computers and vector processors have 15 been limited to "strictly parallel" execution modes. For purposes of this disclosure, strictly parallel execution refers to performing the same operation on each of the different data streams (in the case of SIMD) or on each of the elements in a vector (in the case of a vector processor).

Many computationally intensive applications, however, require the performance of related but different operations, in parallel, on related data structures. Complex math is an 20 example of such an application. In complex math, each variable includes a real element and an imaginary element. Due in large to the sign inversion that occurs when a pair of imaginary components are multiplied, complex math computations require different operations on different parts of the variables. Complex math is but one example of an application that is somewhat constrained by the strictly parallel organization of conventional SIMD machines and vector 25 processors. It would be desirable to implement a processor enabling vector-type processing on related data structures while permitting variations in the operations that are performed on the data structures.

## SUMMARY OF THE INVENTION

The objective identified above is achieved according to the present invention by a microprocessor including an execution unit enabled to execute an asymmetric instruction, where 5 the asymmetric instruction includes a set of operand fields and an operation code (opcode). The execution unit is configured to interpret the opcode to perform a first operation on a first set of data indicated by the set of operand fields and to perform a second operation on a second set of data indicated by the set of operand fields, wherein the set of operand fields indicate different sets of data with respect to the first and second operations and further wherein the first and 10 second operations are mathematically different.

## BRIEF DESCRIPTION OF THE DRAWINGS

15 Other objects and advantages of the invention will become apparent upon reading the following detailed description and upon reference to the accompanying drawings in which:

FIG 1 is a block diagram of selected elements of a processor according to one embodiment of the present invention;

20 FIG 2 illustrates selected element of a vector unit suitable for use in the processor of FIG 1;

FIG 3 is a conceptual illustration of an instruction format for use in the processor of FIG 1 and vector unit of FIG 2; and

FIG 4 is a listing of exemplary instructions supported by the processor of FIG 1 using the vector unit of FIG 2.

25 While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof are shown by way of example in the drawings and will herein be described in detail. It should be understood, however, that the drawings and detailed description presented herein are not intended to limit the invention to the particular embodiment disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within 30 the spirit and scope of the present invention as defined by the appended claims.

## DETAILED DESCRIPTION OF THE INVENTION

Generally speaking, the present invention contemplates a data processing device and system that supports one or more "asymmetric" instructions. Asymmetric instructions, as used 5 herein, are instructions that produce parallel, but different, processing of related data elements.

Referring now to the drawings, FIG 1 illustrates selected elements of a processing device (processor) 100 according an embodiment of the present invention emphasizing the use of a vector unit 200 to achieve asymmetric SIMD functionality. In the depicted embodiment, processor 100 is shown as including a fetch unit 111 that provides a next instruction address 113 10 to an instruction memory 112. Instruction memory 112 responds to the next instruction address signal 113 by providing processor-executable instructions to a decode unit 114. Decode unit 114 is responsible for evaluating the operation codes (opcodes) of the received instructions and for fetching operands from the appropriate register files (connections between decode unit 114 and register files 132, 134, and 136 are not shown in FIG 1 to improve the clarity of the drawing).

15 The depicted embodiment of processor 100 includes a number of functional or execution units. These units include a branch unit (BU) 120, a load/store unit (LSU) 121, an arithmetic logic unit (ALU) 122, a floating-point unit (FPU) 124, and a vector unit 200. In addition, processor 100 includes a data memory 130 accessible to LSU 121, a general purpose register (GPR) file 132 accessible to ALU 122, and a floating-point register (FPR) file 134 accessible to 20 FPU 124.

Branch unit 120 evaluates the results of branch instructions to provide fetch unit 111 with a next instruction address when a branch is taken. LSU 121 is configured to retrieve data from and store data to data memory 130. Processor 100 is a load-store processor in which access to data is restricted to a class of load/store instructions. All arithmetic instructions operate on data 25 in the various register files. ALU 122 is an arithmetic unit for performing operations on scalar, integer data. FPU 124 is used to perform scalar floating-point instructions on data stored in FPR file 134. Execution units 120 through 124 will be familiar to those skilled in the design of general purpose microprocessors.

In addition to the conventional execution units 120 through 124, processor 100 according 30 to one embodiment of the invention includes vector unit 200. Vector unit 200 is configured to support the execution of a single vector-type instruction that produces a first operation on a first

set of data elements and a second operation on a second set of data elements where the first and second operations are different. Thus, vector unit **200** supports asymmetric vector instructions. Moreover, although the following description is presented in the context of a vector unit **200** that includes a vector register file, the invention encompasses, with appropriate modifications, scalar register file implementations.

Turning now to FIG 2, selected elements of vector unit **200** of FIG 1 are depicted to emphasize the unit's flexibility. In the depicted embodiment, a vector register file **201** is implemented with a primary FPR **202** and a secondary FPR **204**. Thus, the depicted implementation of vector register file **201** has a "rank" of two. Other implementations may 10 employ a vector register file with more than two register elements per entry. Operation of vector unit **200** will be illustrated using a floating-point, complex arithmetic application. In this context, each of registers in primary and secondary registers **202** and **204** are preferably floating-point registers of 64 bits in width to accommodate double precision floating-point calculations.

Data is retrieved from and stored back to a data memory (not shown in FIG 2) via a data bus **250**. The depicted implementation of data bus **250** is a 128-bit data bus capable of carrying two 64-bit doublewords. The data memory to which vector unit **200** is connected may be the data memory **130** of FIG 1 or it may be a dedicated vector data memory that is not depicted. In the context of a complex arithmetic application, 128-bit data bus **250** may carry, at any given time, a 64-bit floating-point representation of a real portion of a complex number and a 64-bit 20 floating-point representation of an imaginary portion of a complex number. In such a case, data arriving via data bus **250** may be stored such that the 64-bit real portion of the complex number is stored in one of the 32 registers (P0 through P31) of primary register file **202** while the 64-bit imaginary portion of the complex number is stored in the corresponding register (S0 through S31) of secondary register file **204**. If the real portion of a complex number is stored in register 25 P0 of primary register file **202**, the imaginary portion of the number is stored in register S0 of secondary register file **204**.

An important feature of vector unit **200** is emphasized by the multiplexers **210** and **212** at the input to vector register file **201**. These multiplexers, in conjunction with a set of supported instructions, enable reordering and/or replication of data arriving via bus **250** as it is stored into 30 register file **201**. Similarly, the multiplexers **240** and **242** at the output of vector register file **201** enable reordering or replicating of data as it is stored back to the memory via bus **250**.

As it is implemented in FIG 2, for example, the 128-bit bus **250** divides into a pair of 64-bit data busses **251** and **252** at the input to vector register file **201**. The output of vector register file input multiplexer **210** provides an input to primary register file **202** while the output of multiplexer **212** provides an input to secondary register file **204**. Multiplexers **210** and **212** both 5 receive the first and second 64-bit busses **251** and **252** as inputs. The select signals (not depicted explicitly) of each multiplexer determine which of the two busses (**251** or **252**) will provide the input to the corresponding register file (**202** or **204**).

In the depicted implementation, in which each vector register in vector register file **201** includes two elements (i.e., the primary vector register element and the secondary vector register 10 element), multiplexers **210** and **212** enable at least four possible conditions, namely, data from bus **251** is stored in primary register file **202** and data from bus **252** is stored in secondary register file **204**; bus **251** data is stored in both of the register files (replication); bus **252** data is stored in both of the register files (a second replication example); and bus **251** data is stored in secondary register file **204** while bus **252** data is stored in primary register file **202** (reordering of 15 data).

Data reordering and replication as data is stored back to memory is implemented with a pair of output multiplexers **240** and **242**, which each receive a pair of 64-bit inputs, namely, the contents of a primary side source register ( $S_P$ ) and the contents of a secondary side source register ( $S_S$ ). The outputs of multiplexers **240** and **242** are 64-bit busses **253** and **254** 20 respectively. Busses **253** and **254** are merged into the 128-bit outbound data bus **250** that delivers data to the data memory on a vector register store command. The select signals for multiplexers **240** and **242** (not shown) determine whether the busses **253** and **254** carry data from primary vector register file **202** or secondary vector register file **204**. Accordingly, dependent on 25 the state of multiplexers **240** and **242**, outbound data bus **250** may carry primary side data on one half of bus **250**, secondary side data on the other half (in either order), primary side data on both sides of bus **250** or secondary side data on both sides of data bus **250**.

Reordering and duplication of data as it is loaded into and stored back to memory from vector register **201** has the potential to improve the efficiency and performance of certain application and calculations. Moreover, data reordering and duplication, as enabled by the 30 vector unit **200** depicted in FIG 2 is achieved automatically depending upon the state of the multiplexer select signals. These select signals, in turn, can be controlled via bits in the opcode

of a vector register load. Referring to FIG 3, an exemplary format for an instruction **300** suitable for implementing data reordering and duplication during vector register load (and store) instructions is depicted. In the depicted embodiment, instruction **300** includes a two part opcode field **302-1** and **302-2**, a target/source register field **304**, an "A" operand register field **306**, a "B" operand register field **308**, and a "C" register operand field **310**. For use with the embodiment of register file **201** as depicted in FIG 2, the target/source register field **304** and each of the register operands field **306**, **308**, and **310** each comprise five bits for specifying one of the 32 registers. In this implementation, a 32-bit instruction would include 20 bits for specifying registers and 12 bits remaining for specifying opcodes and possibly other control information.

10 Referring to FIG 4, an exemplary table of some of the instructions supported by vector unit **200** is presented to emphasize selected elements of the invention. With respect to the load/store reorder/duplication capabilities, for example, vector unit **200** supports a set of instructions (indicated by reference numeral **402**) that includes load/store double word instructions, load/store cross instructions, and load/store replicated instructions. The load/store 15 cross instructions, as indicated by their corresponding functional descriptions, achieves reordering of data (relative to the conventional load/store doubleword instructions) by loading/storing the first 64-bits of data bus **250** into/from secondary register file **204** (FIG 2) while loading/storing the second 64-bits into/from primary register file **202**.

20 Vector unit **200** as depicted in FIG 2 includes additional elements that emphasize an additional feature, namely, the ability to perform cross-type arithmetic instructions and asymmetric instructions using a single instruction. Specifically, the depicted implementation of 25 vector unit **200** includes a pair of 3-input arithmetic units, a primary ALU **220** and a secondary ALU **230**. In an embodiment suitable for use in complex math and other intensive calculations, ALU's **220** and **230** are both double precision floating-point units each of which can receive three floating-point inputs. Moreover, each of the floating-point unit inputs can accept data from either primary side register file **202** or from secondary side register file **204**. Specifically, primary ALU **220** includes an "A" input **221** connected to the output of an "A" multiplexer **222**, a "C" input **223** connected to the output of a "C" multiplexer **224**, and a "B" input **225** connected to the output of a "B" multiplexer **226**. Similarly, secondary ALU **230** includes an "A" input **231** 30 connected to the output of an "A" multiplexer **232**, a "C" input **233** connected to the output of a "C" multiplexer **234**, and a "B" input **235** connected to the output of a "B multiplexer **236**. This

arrangement of multiplexers beneficially enables primary side ALU 220 and secondary ALU 230 to select inputs from either side of vector register file 201. This architecture provides the support for a variety of compound, cross-register, and asymmetric vector floating-point instructions.

Referring to FIG 4 again, the exemplary instruction set 400 supported by vector unit 200 includes compound, parallel instructions such as the Vector Parallel Mult/Add Instruction (403) that performs a floating-point multiplication and add operation on a set of three input variables in parallel (i.e., on each side of vector register file 201) such that a result is generated and stored in primary register file 202 based on inputs retrieved from register file 202 while a second result is generated and stored in secondary register file 204 based on inputs retrieved from register file 204. Variations of this parallel compound command supported by vector unit 200 include a "negate" form of the instruction in which the result is multiplied by -1, a "subtract" form of the instruction in which the B operands are subtracted from the product of the A and C operands rather than added, and a negate subtract form in which the B operands are subtracted from the product and in which the final result is multiplied by -1.

Additional variations of the multiply add commands supported by vector unit 200 include "cross" commands in which the instruction's registers (target and source) are not all on the same "side" of vector register file 201. Representative of this class of instructions is the cross multiply and add instruction (405) in which the B, C, and T operands are on one side of vector register file 201 while the A operand is taken from the opposite side of the file. (i.e.,  $A_S C_P + B_P \rightarrow T_P$  and  $A_P C_S + B_S \rightarrow T_S$ ). Variations of the cross commands include cross negate commands (result is multiplied by -1), cross-subtract commands (the B operand is subtracted from the product of the A and C operands), cross-subtract-negate (combination of the subtract and negate commands).

In addition to the basic cross-command variations, vector unit 200 includes support for a set of cross-replicate commands exemplified by the cross replicate primary command (406). In this type of command, at least one of the operands is common to the operation performed on both sides of the vector file (i.e., one operand is command to ALU 220 and ALU 230). In the exemplary instruction set of FIG 4, the replicated operand is the A operand, but this is an implementation detail and other operand(s) could serve as the replicated operand(s). The replicated operand may come from primary register file 202 or from secondary register file 204.

A further feature of vector unit 200 and instruction set 400 includes support for asymmetric and complex vector instructions exemplified by the instruction 407 and its

derivatives. In an asymmetric instruction, the mathematical operation performed by the primary side ALU 220 in response to a particular instruction is different than the mathematical operation performed by the secondary ALU 230 in response to the same instruction. Thus, as depicted in instruction 407, the primary side ALU 220 adds B operand to the product of the A and C 5 operands while the secondary side ALU 230 subtracts the B operand from the product of the A and C operands and negates the result. The instruction 407 further incorporates a cross operand feature in which the A operand is replicated in both ALU's, but it will be appreciated that the instruction's asymmetry (difference in mathematical operations) and replication (duplication of operands) are independent elements.

10 The complex instructions supported by instruction set 400 and vector unit 200 include the instruction identified by reference numeral 408 and its derivatives. Complex instruction 408 is a specific combination of the cross and asymmetric instructions described above. Complex instruction 408, for example, duplicates the A operand in both ALU's, crosses the C operands, and performs a multiply/add on one side while performing a multiply/subtract and negate on the 15 other side. The complex instructions derive their name from their particular suitability for performing complex multiplication. These instructions enable the inherently asymmetric complex operations to be performed with fewer instructions and fewer register accesses than is possible in strictly parallel SIMD machines. The result is fewer register resource contentions, more instruction slots available for other operations (e.g., loads) and higher computational 20 throughput.

20 The preceding description describes the use of asymmetric instructions in the context of a vector register file 200. In other embodiments, the asymmetric instructions are implemented in the context of a scalar (non-vector) register file. In such an implementation, a single instruction would perform a first operation on a first set of operands and a second operation on a second set 25 of operands where the first and second operations differ. The first and second sets of operands might be limited to two registers each to simplify instruction execution. An instruction of the form ASYMMULT (A, B, C) might, for example, multiply the contents of register A times the contents of register B and store the result in C and multiply the contents of register A+1 times the contents of register B+1, negate the result and store the result in register C+1.

30 It will be apparent to those skilled in the art having the benefit of this disclosure that the present invention contemplates a mechanism for securing a pair of mated cable connectors. It is

understood that the form of the invention shown and described in the detailed description and the drawings are to be taken merely as presently preferred examples. It is intended that the following claims be interpreted broadly to embrace all the variations of the preferred embodiments disclosed.